



A CHEMICAL AND BIOLOGICAL ASSESSMENT  
OF WATERS IMPACTED BY  
ACTIVE GOLD MINING OPERATIONS  
IN THE RED LAKE AREA

AUGUST, 1982

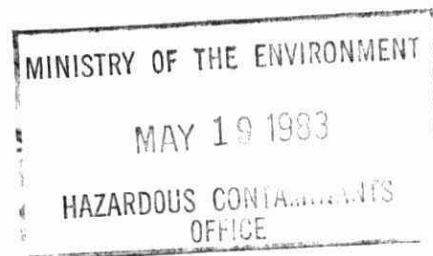
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IN THE RED LAKE AREA



TECHNICAL SUPPORT SECTION  
ONTARIO MINISTRY OF THE ENVIRONMENT  
NORTHWESTERN REGION

April, 1982

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## SUMMARY

Gold mining and processing operations conducted by Campbell Red Lake Mines Limited and Dickenson Mines Limited since the late 1940's have seriously impaired and continue to impair the waters of Balmer Lake and Balmer Creek but there has been little impact on the water quality of the Chukuni River and receiving waters farther downstream. Balmer Lake was used for many years for unconfined disposal of mill tailings (spent ore). In recent years, the mining companies have agreed to construct impounding dykes both to limit further tailings migration and to provide physical conditions which facilitate effluent treatment. The construction of the necessary dykes and impounding facilities has proceeded. These measures were not designed to restore the portion of Balmer Lake which remains outside the impoundments. The above remedial measures were intended primarily to provide proper control of effluent from milling operations.

Waters in the portion of Balmer Creek below Balmer Lake are unable to maintain a normal aquatic community because of severe environmental stress caused by water quality and substrate alterations. Adverse biological conditions are reflected by the absence of fish, absent or reduced macroinvertebrate populations and major reductions in phytoplankton diversity. Waters in the Balmer Creek watershed were found to be toxic to clams (organisms sensitive to mining wastes) in a two to four week test period, but did not prove toxic to rainbow trout fingerlings in a 96-hour static bioassay.

Likely causes for many of these adverse biological changes are derived from a physical-chemical water quality evaluation which indicates that potentially toxic concentrations of arsenic, cyanide and a number of heavy metals including copper, zinc, nickel, and cobalt are present in much of the watercourse. Other adverse changes include sharply elevated nutrient (phosphorus and nitrogen), turbidity, and conductivity values. Many parameters monitored for toxicological purposes had concentrations an order or orders of magnitude higher than background levels and most

exceeded the Provincial Water Quality Objectives for the protection of aquatic life. Arsenic levels in Balmer Creek also exceed the Ministry objective for public drinking water supplies. No public or private supplies are taken from the creek at this time.

Sediments were contaminated with a number of heavy metals including arsenic, chromium, copper, zinc and cobalt. Arsenic comprised a small percentage of sediments in some cases. Much of the sediment in Balmer Lake and Balmer Creek is derived from previously discharged tailings.

The effect of the Balmer Creek influx on the Chukuni River system appears minor; macroinvertebrate populations and diversity are affected in a localized zone extending approximately one-half of a kilometre downstream of the Balmer Creek-Chukuni River confluence. Minor changes in water quality are observed at the Chukuni River station downstream of Balmer Creek when compared to the upstream (control) values. Monitored waters in Red Lake, the Chukuni River, and Keg Lake are considered good to excellent. These waters meet Ministry criteria for public recreation and for the protection of aquatic life.

Mercury levels found in the dorsal muscle of walleye taken from Red and Keg Lakes are typical of mercury levels found in walleye obtained from many other undeveloped lakes in north-western Ontario. Mercury levels in walleye in Keg Lake downstream of Balmer Creek are lower in comparison to similar-sized fish from Red Lake.

## RECOMMENDATIONS

Although Balmer Lake is not presently capable of supporting a normal aquatic community, it is expected that with additional waste treatment, the water quality at the outlet of Balmer Lake will meet the provincial water quality objectives for the protection of aquatic life. It is recommended, therefore, that a mass

balance for the known contaminants; particularly arsenic, copper, cyanide, zinc and nickel, be conducted on the Balmer Lake system. Loadings from both industrial operations and the Balmer Lake outflow should be accurately assessed. This can be achieved through the installation of proper flow measuring devices to quantify the discharge volumes at the two mill outfalls and the outlet to Balmer Creek. Coupled with an intensive effluent and water quality sampling program, such action will enable the Ministry to assess the relative contributions of industry, Balmer Lake and watershed dilution water to the overall character of Balmer Creek water quality and provide data for selecting the most effective abatement strategy. It is recommended that such an abatement strategy be chosen with consideration for the concept that the Provincial Water Quality Objectives for the protection of aquatic life be met at the outlet to Balmer Lake.

## INTRODUCTION

A preliminary investigation in 1971 by The Ontario Water Resources Commission, the predecessor agency of the Ministry of the Environment, suggested that the Balmer Lake/Balmer Creek system in the Red Lake vicinity was seriously contaminated by excessive concentrations of certain heavy metals/metalloids and cyanides as the result of local gold mining operations. Results released in 1978 from a routine water quality monitoring program in the Balmer Creek locale supported the initial findings. Subsequently, in 1978 and 1979, the Ministry intensively investigated water quality, sediments, and selected biota to determine the scope of and to estimate the severity of the contamination of the environment. Additionally, a number of undeveloped nearby lakes were surveyed for comparative purposes. Results of these studies are presented and discussed. Limitations on the use of these waters are documented.

## DESCRIPTION OF THE STUDY AREA

Red Lake is located in the Patricia portion of the District of Kenora, approximately 200 kilometres northwest of Kenora. The Red Lake area lies nearly midway between the Berens River to the north and the English River to the south. The Balmer Creek watershed, a few kilometres east of Red Lake (Figure 1), receives wastes from Campbell Red Lake Mines Limited and Dickenson Mines Limited, two gold mining companies that have operated continually since the late 1940's. The gold is extracted from a number of chalcophilic ores including pyrite ( $\text{FeS}_2$ ), pyrrhotite ( $\text{Fe}_{1-x}\text{S}$ , where  $x = 0.0-0.2$ ), arsenopyrite ( $\text{FeAsS}$ ), sphalerite ( $\text{ZnS}$ ), and galena ( $\text{PbS}$ ), after the ore is removed at both mining complexes by conventional underground methods. After the ore is crushed and ground, gold is concentrated through amalgamation, floatation, cyanidation, roasting, and refining. Balmer Lake serves as the approved tailings (spent ore) disposal area for both mining operations. Tailings and processing materials from Dickenson Mines Limited are piped across Balmer Creek and discharged near the southeast corner of Balmer Lake without treatment. A dam has since been completed to prevent the further loss of tailings into Balmer Lake. Wastes from Campbell Red Lake Mines Limited are discharged directly into Balmer Lake after a buffering treatment designed to precipitate soluble arsenic. In 1978, dams were constructed to confine tailings from the Campbell operation to the west side of Balmer Lake. However, much of Balmer Lake and the downstream creek is underlain by tailings released in prior years.

Balmer Lake has an area of approximately 250 hectares with a mean depth of approximately 2 metres. This "lake" drains southward via Balmer Creek through an old tailings disposal area into the Chukuni River. The Chukuni River also receives runoff from the Red Lake watershed. The Chukuni River flows through Keg, Gull Rock, Two Island and Pakwash Lake and into the English River eventually joining the Winnipeg River near the Ontario-Manitoba border.



The topography and physiography of the Red Lake area is typical of Precambrian Shield areas in northern Ontario. The Red Lake basin is occupied by volcanic formations of the Keewatin age, sedimentary deposits of the Timiskaming age, and later intrusive rock formations of several ages. The topography of the area, characterized by low ground and rolling hills, is controlled to some extent by siliceous sediments and iron formations which form ridges. Most of the Red Lake area is covered with a thick coating of glacial clay, sand, and boulders. In general, hills and ridges are rounded. Valleys are not deeply incised and most are poorly drained and swamps are common.

## METHODS

### WATER MONITORING

Water sampling sites, in general, were selected to utilize and complement the ongoing water quality monitoring program (Stations 2, 3, 6, 8 and 10 in Figure 1). Sites 1 to 4 were control sites. Station 5 was centrally established in Balmer Lake after a short investigation with a conductivity meter. Results demonstrated that the total quantity of dissolved ions at this site was typical of over 90 percent of the lake. Stations 6 to 11 were established for direct assessment purposes. Results from cross-sectional conductivity studies of the Chukuni River at site 10 indicated that waters from Balmer Creek were well mixed laterally and vertically at this point. All samples were obtained from near-surface waters with the exception of site 11, Keg Lake, where waters 1 metre off the bottom were also monitored. Preliminary survey investigations indicated that Keg Lake is capable of recycling potentially toxic substances that may be introduced via the Balmer Creek-Chukuni River drainage. At lake turnover, substances which have accumulated in the hypolimnion may be mixed and redistributed throughout the water column and subsequently carried further downstream.

Waters were sampled at all sites on May 15, August 16, October 10, 1978 and April 4, 1979 with a plastic Kemmerer sampler. When necessary, samples were preserved according to standard Ministry procedures. Perishable constituents were usually analyzed within 48 hours at the Ministry Laboratory in Thunder Bay. Samples were tested for basic physico-chemical properties plus a number of heavy metals/metalloids that may have been present due to the mining of sulphuritic ores.

Temperature and dissolved oxygen measurements were determined in the field with a YSI Model 57 dissolved oxygen meter. Analyses were conducted for turbidity, colour, total solids, suspended solids, hardness, conductivity, alkalinity, acidity, sulphate, chloride, calcium, magnesium, potassium, sodium, manganese, iron, zinc, silver, copper, nickel, lead, cadmium, cobalt, chromium, aluminum, molybdenum, titanium, vanadium, barium, tin, strontium, selenium, tellurium, arsenic, boron and cyanide.

Subsurface water samples were collected on August 16, 1979 from fixed-wing aircraft from a number of undeveloped lakes, namely, Little Vermilion, Walsh, Ranger, Unnamed, Trout, Hamel and Pot Hole (Figure 2). The samples were analysed for basic physico-chemical parameters and for heavy metals similar to those outlined for the routine survey. Lakes which stratify, such as Trout and Hamel, were also sampled 1 metre off the bottom.

## SEDIMENTS

Duplicate cored sediment samples were obtained from all sites (Figure 1) with a weighted "Phleger" corer or, when feasible, with core tubes inserted by hand and capped. Cores were also procured from a number of undeveloped lakes (Figure 2), some of which were sampled with the aid of fixed-wing aircraft. Cores were split into 0-5, 5-10, 10-15, 15-20, and 20+ centimetre sections and a brief visual description of each portion was recorded. Samples were then forwarded to the Ministry of the Environment Laboratory in Toronto where emission spectrographic analyses were conducted on dried sediments for a number of heavy metals. Loss on ignition was also determined on all samples.

## MACROINVERTEBRATES AND PHYTOPLANKTON COLLECTIONS

On August 15, 16, and 17, 1978, macroinvertebrate samples were collected from sites on Red, Keg and Balmer Lakes, the Chukuni River, and Balmer Creek (Figure 3). All samples from sites on Red and Keg Lakes and the Chukuni River and from stations 3, 4 and 5 on Balmer Creek were obtained with a ponar dredge (0.053 m<sup>2</sup> sampling area) and washed through a box screen (0.65 mm hole opening). Samples from Balmer Lake and station 1B of Balmer Creek were obtained with a petite ponar dredge (0.028 m<sup>2</sup> sampling area) and washed as above. At stations 1A and 2 on Balmer Creek, qualitative samples were obtained with a hand sieve.

After the samples were washed, the macroinvertebrates were sorted from the extraneous material in the field and then deposited in 95 percent ethyl alcohol for storage.

On August 17, 1978, single phytoplankton samples were collected from Red, Keg, and Balmer Lakes. The samples, obtained with a composite sampler lowered through the euphotic zone (2 x secchi disc depth), were preserved with Lugol's iodine solution.

## BIOASSAYS

Two separate bioassays were employed to help biological assessment of the receiving streams; a static 96-hour toxicity test using rainbow trout Salmo gairdneri fingerlings, and in situ experiments utilizing caged indigenous clams were conducted. The static bioassay was performed by the Ministry Limnology and Toxicity Section in Toronto on 50-litre samples received within 24-hours from selected sites in the Red Lake area (Figure 4). Five to ten trout were exposed for 96 hours in aerated samples held at 15°C and fingerlings mortality was documented. Samples proving acutely toxic were analysed for suspected contaminants.

The second bioassay involved the strategic relocation of native clams Anadonta grandis from Red Lake to waters chemically

affected by mining operations (Figure 4). Sites were selected primarily on the basis of the results obtained from the regional water quality monitoring program. At each station, twenty clams were placed in a 20 x 20 x 15 cm wire cage and mortality over a two-month period was documented.

#### WALLEYE COLLECTIONS

During August, 1978, attempts to collect walleye Stizostedion vitreum vitreum were undertaken at Red, Keg and Balmer Lake with gill nets, the mesh sizes of which ranged from 3.8 to 11.4 cm (1½ to 4½ inches) and lengths of which varied from 33 to 76 metres (100-250 feet). Nets were set in near-shore areas and checked daily until at least twenty specimens, spanning most size classes, were obtained. Two days were needed to obtain the required fish from both Keg and Red Lakes; 160 m of net was utilized. Attempts to collect fish from Balmer Lake over a four-day period were unsuccessful.

After captured walleye were weighed and measured for length, a portion of the epaxial muscle was removed for mercury and arsenic analysis. Samples were placed in sterile plastic bags, frozen, and forwarded to the Ministry of the Environment Laboratory, Environmental Trace Contaminants Section, Toronto, for analysis.

#### RESULTS AND DISCUSSIONS

##### WATERS

An accurate physico-chemical characterization of waters forms the basis for many Ministry assessments. Results from the study area are compared with criteria established for the protection of public health, aquatic biota, and where applicable, livestock watering and other agricultural purposes. Because the biogeochemical characteristics of waters continually change

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during the year, samples were collected during each of the four seasons. This data base is considered a minimum for certain parameters and does not cover all aspects of contaminant cycles in river and lake environments. The data do, however, provide indications of general water quality.

Mean values for selected physico-chemical parameters (Table 1) indicate gross contamination of the Balmer Creek watershed; however, waters downstream of the Balmer Creek-Chukuni River confluence remain largely unaffected by mining operations. Other monitored waters in Red Lake are deemed good to excellent.

Since this study encompassed two watersheds, a minimum of two control sites (stations 1 and 4) were required; natural biogeochemical differences between Balmer Creek and Chukuni River basins are reflected in fundamental differences in the aquatic chemistry. Natural variations in water quality between basins must be recognized for one to evaluate the degree of impairment. In the absence of any industrialization-urbanization of the Balmer Creek watershed, waters draining into the basin would be considered inferior to those of the Chukuni River system, based upon present standards which equate high water quality with low biological productivity and high transparency. Supporting evidence is derived from a comparison of the Balmer Creek control station with the Chukuni River reference station (site 1). The former station clearly has higher phosphorus, turbidity and colour results. Consequently, this evaluation will proceed in two parts. The effects of mining operations on water quality will be considered first on Balmer Creek flows and second, on the Chukuni River system.

Excessive nutrient enrichment, high dissolved and total solids levels, and elevated concentrations of a number of heavy metals are indicative of the serious impairment of the portion of Balmer Creek downstream from Balmer Lake.

Results from the control site on Balmer Creek (station 4) indicate that these waters are typical of many undeveloped streams in northwestern Ontario. Concentrations of nutrients (nitrogen

and phosphorus) are moderate while turbidity and suspended solids levels are low. All colour values exceeded 70 Hazen Units, as is typical of northern waters stained by naturally occurring soluble organic compounds. These soluble organic compounds are also responsible, presumably, for the relatively high iron concentrations of 0.67 ppm which exceed the Province-wide criterion of 0.3 mg/l for the protection of aquatic life. Since many dystrophic waters naturally have iron levels in excess of the 0.3 ppm (Table 2), due primarily to organically bound nontoxic iron, concentrations at this site (Table 2) are not considered deleterious to the ecosystem.

Concentrations of other metals/metalloids, cyanide and other parameters are exemplary of many other shield waters.

In contrast to the control site, other stations in the Balmer Creek system have been adversely affected by mining operations and municipal wastes as evidenced by moderate to sharp increases in phosphorus, nitrogen, turbidity, conductivity, cyanide, and a number of heavy metals/metalloids. Generally, differences among sites are not significant with the exception of minor changes downstream of site 6 which are attributed to sewage input from the town of Balmertown (S.T.P.).

Total and soluble phosphorus levels were approximately one order of magnitude or ten times higher than the control value of 0.027 mg/l. Nitrogen levels also increased radically with nitrate, the key nitrogen macronutrient affecting productivity, having levels two to three orders of magnitude greater than the background level of 7 µg/l. In the absence of any toxic components introduced into this system, these data would indicate extremely fertile waters. Although intensive productivity studies were not carried out in Balmer Lake, concentrations of algae do not visually appear to pose an environmental problem; therefore, other factors are likely inhibiting phytoplankton growth.

Conductivity levels were usually four to five times higher than the control site value of 81 µmhos/cm. Since conductivity



is directly related to the quantity of dissolved solids (dissolved solids are approximately equal to two-thirds of the conductivity), the Balmer Lake watershed clearly does not meet the following Provincial Water Quality Objective. This objective states that to protect aquatic life, dissolved solids loadings should not increase the concentrations by more than one-third of the natural level.

The aesthetic value of the stream is reduced because of elevated turbidity and suspended solids values. These changes indicate a decrease in the clarity of the waters affected by mining operations.

Alkalinity and pH results indicate that acid generation and pH depression are not of concern. In fact, the pH of Balmer Lake and downstream Balmer Creek is approximately one-quarter to one-half pH unit higher than the control site. This increase is primarily the result of a pH adjustment practice by Campbell Red Lake Mines Limited which ensures that the mine effluent is well buffered.

Microbiological results are elevated in comparison to the control site; however, counts observed are well within the Ministry criteria for water contact recreational pursuits. Higher counts were anticipated due to the discharge of municipal sewage with ineffective treatment. It may well be that the toxicity of metals, etc., resulting from industrial discharges exercised some control over bacterial populations in the creek. The low water temperatures prevailing at the times of several of the sampling runs may also have resulted in a data set not typical of microbial populations during summer months.

Cyanide results are also sharply elevated; however, total (not free) cyanide results are presented. Due to the relatively fast decomposition of free cyanides, data reflect the concentrations of stable cyanide complexes since the residence time in Balmer Lake should be adequate for free cyanide breakdown. Supporting evidence comes from results from the 1979 water quality monitoring program. Total and free cyanide tests on the same



sample taken from the outlet of Balmer Lake on September, 1979, yielded results of 0.23 mg/l and less than 0.01 mg/l respectively. At worst, free cyanide levels could only be two times the P.W.Q.O. (0.005 mg/l). Toxicity of complexed cyanides is substantially lower than the toxicity of free cyanide and, from all available information, cyanide concentrations do not appear to be of major concern at most sites.

Concentrations of metals/metalloids including arsenic, zinc, nickel, copper, cobalt, manganese, iron, strontium, and antimony were generally one to two orders of magnitude higher than the control sites. Other elements such as molybdenum, cadmium, vanadium, barium, silver, selenium, and mercury were also elevated, but to a lesser degree.

The following table clearly shows that the Ministry objectives for the protection of aquatic life have been exceeded for a number of these elements in the Balmer Creek system.

Range of Mean Concentrations Observed in Balmer Creek

| Parameter | Watershed<br>(mg/l) | P.W.Q.O.<br>(mg/l) |
|-----------|---------------------|--------------------|
| Arsenic   | 0.57-0.79           | 0.1                |
| Copper    | 0.23-0.51           | 0.005              |
| Zinc      | 0.09-0.17           | 0.03               |
| Nickel    | 0.23-0.45           | 0.025              |
| Iron      | 0.71-1.8            | 0.30               |

One must recognize, however, that objectives are based upon the assumption that all metals measured are in a toxic form since currently there is no standard technique to measure the toxic component. Consequently, total concentrations in a given surface water could exceed the objectives without damage to any aquatic life. When certain contaminants exceed objectives by an order of

magnitude or more, however, adverse effects on some part of the ecosystem are probable. Although Provincial objectives have not been set for aluminum, vanadium, barium, molybdenum, strontium, boron, cobalt, and antimony, some of these metals, i.e. cobalt and antimony, are toxic in low concentrations and may contribute significantly to the impairment of this watercourse. Concentrations of arsenic also exceed the Ministry criterion of 0.05 mg/l for public consumption. While mercury levels are elevated, the criterion is based upon limiting accumulative effects in organisms, particularly fish. Mercury levels, here, are not of concern since results for fish sampled in the Red Lake area are comparable to those of other fish from uncontaminated waters in northwestern Ontario (see Fish Contaminant Monitoring).

Waters impaired by mining operations are restricted primarily to the Balmer Creek watershed. Comparison of values at sites upstream and downstream of the Balmer Creek-Chukuni River confluence (stations 1 and 10) indicate generally minor changes in water chemistry, therefore, substantial dilution of contaminants leaving Balmer Creek must occur. Of most concern is the moderate increase in phosphorus levels from 0.021 to 0.034 mg/l. These data suggest that increases in productivity in Keg Lake are likely. Copper, nickel, and zinc levels are also elevated in comparison to the results obtained at the control site; however, only copper exceeded the Provincial Water Quality Objective at sites downstream of Balmer Creek.

In the bottom waters of Keg Lake, concentrations of many parameters are elevated in comparison to the results obtained from surface waters. This phenomenon, however, is natural.

All waters monitored outside the Balmer Creek watershed are considered to be of good quality.

## SEDIMENTS

One of the most sensitive techniques available for delineating the geographical extent of waters affected by mining operations involves detailed heavy metal analysis of cored samples of

the sediments underlying the receiving stream. Salient advantages of utilizing this technique include the following:

- (1) In an ecosystem, sediments are usually the primary sink for heavy metals either through direct ab/adsorption from the water column or through the deposition of metal enriched suspended particulate. Intermittent increases in the metal concentrations in the water column, which frequently are undetected unless a high frequency sampling program is instituted, will ultimately be reflected in the substrate.
- (2) Sediments provide a time-integrated continuum whereby properties of the substrate prior to the commencement of mining operations can be determined. In many shield lakes, sedimentation rates approximate 1 mm per year. Thus, in a lake environment impacted by anthropogenic metal releases beginning half a century ago, a pristine matrix can generally be procured at a depth of 5 to 10 centimetres, depending upon the degree of vertical mixing by bottom dwelling organisms and chemical processes.
- (3) In an uncontaminated ecosystem, concentrations of various heavy metals and sediments can vary naturally by over an order in magnitude, as a result of physical-chemical characteristics of the substrate (i.e. particle size and organic content). For example, mercury concentrations in organic-rich sediments at a lake centre are frequently over ten times higher than results obtained from a sand substrate from near-shore waters. When metal levels in a core profile are compared, however, the surface enrichment or nonenrichment of an element in a contaminated watercourse is of more significance than the actual values observed, since the sediment bioassay science is in its infancy and there is insufficient information to adequately predict toxic effects based upon sediment biogeochemistry.

As the result of prior studies in the Red Lake area, contamination of Keg and Gull Rock Lakes was expected to be of minor significance. Selected results (Table 3) of tests on duplicate

cores collected 1 m apart from both lakes in July, 1978 generally confirm this assumption. Although surface enrichment for arsenic, copper, lead, and nickel is evident in all cores, the metal results for surface sediments were at worst only four times the deeper (uncontaminated) values and warrant minimal attention. Surface arsenic concentrations were enriched by a factor of ten; however, these values are orders of magnitude lower than concentrations at upstream sites. Since the analysis of other elements including boron, vanadium, and strontium indicates little or no surface enrichment, additional surveys were conducted upstream of and including Gull Rock Lake closer to the waste-bearing discharges from Balmer Creek. For cores procured at each lake, results for comparable subsections were in good agreement; therefore, for the subsequent survey, data for single cores only are presented.

In July, 1979, sediments were obtained at sites 1 to 8, 11 and 12 (Figure 4). At site 10, a rocky substrate prevented successful coring for sediment. Selected results (Table 3) strongly suggest that the contaminants in Keg and Gull Rock Lakes were derived from mining operations in the Balmer Creek watershed. Surficial sediments from the Chukuni River upstream of the Balmer Creek-Chukuni River confluence and in Red Lake (sites 1, 2 and 3) do not appear enriched with arsenic, nickel, or lead. Furthermore, no trends are evident in metal concentrations in sediment subsections obtained from Balmer Creek upstream of Balmer Lake (site 4). Concentrations of arsenic, lead, and nickel, usually less than 10, 30 and 50 ppm, respectively, were comparable to values observed in off-system lakes (Table 5). Substrate from Balmer Lake and from downstream Balmer Creek sites had strikingly higher nickel and lead values and grossly elevated arsenic concentrations in comparison to the aforementioned sediments. In Balmer Lake, arsenic and nickel values, while decreasing with sediment depth, remain excessive even in the 20-25 centimetre sections. The discharge of large quantities of suspended solids (tailings) into Balmer Lake through industrial operations is presumably responsible for increasing substantially the sedimentation rate at this site.

Not surprisingly, few, if any, gradations for many of the metals are observed in the substrate from Balmer Creek. As previously discussed, this creek flows through an old tailings disposal area and cores at these sites apparently do not penetrate pristine substrate.

At sites 5 to 8, arsenic concentrations are three to four orders of magnitude higher than background and arsenic actually constitutes a small percentage of the sediment. Nickel and lead concentrations are also elevated by factors of approximately 5 and 10, respectively. The substrate in the Balmer Creek watershed affected by mining operations is also enriched with many other metals including zinc, cobalt, chromium, and silver; however, for this section of the report, the presentation of data for arsenic, the most serious contaminant, plus two transition metals is adequate for documenting the distribution of metal-enriched surface sediment. Metal concentrations in sediment profiles for Keg and Gull Rock Lakes are generally comparable to results obtained in 1978.

#### MACROINVERTEBRATES

Of all the various communities in an ecosystem, the macroinvertebrates (bottom fauna) appear to be the most adversely affected group in waters downstream of mining operations. Adverse aquatic conditions result in changes in community structure.

Results of macroinvertebrate collected from Balmer Lake and Balmer Creek are presented in Table 7. No macroinvertebrates were taken in 20 samples collected from stations 1 to 3 on Balmer Lake. Stations 1 and 2 had substrate comprised of finely ground grey rock resembling flour in suspension (tailings).

Upstream of Balmer Lake, stations 1a and 1b were selected as control sites for downstream creek stations. Two controls at Balmer Creek were required, since natural geomorphological changes in a stream influence community structures. At station 1a, waters are shaded, cool and well aerated. Flows at site 1b near

Balmer Lake are sluggish and exposed and the creek contains an abundance of vegetation. In the contaminated creek, station 2, just downstream of Balmer Lake, is an exposed riffle of rock and sand bottom with very little vegetation. Stations 3, 4, and 5 are located progressively downstream on Balmer Creek. Substrate at station 3 is comprised of tailings; at station 4, tailings and detritus; and at station 5, tailings, detritus, and clay. In the absence of any anthropogenic alterations to this system, stations 1a and 2 would be expected to have comparable macroinvertebrate communities, as would stations 1b, 3, 4, and 5. A comparison of taxa between sites 1 and 2 indicates that pollution-intolerant groups such as the Mayflies - Baetinae and Ametropinae, Caddisflies - Polycentropus and Trifaenodites, and Molluscs - Amnicola, Physa and Spaerium that were present at station 1 were absent at station 2. Also, total taxa at stations 3, 4, and 5 of 2, 3 and 3 respectively were sharply lower than the number of taxa at the control station (1b).

Clearly, the macroinvertebrate community has been seriously altered in the Balmer Creek watershed.

On the Chukuni River, most stations are suitable for inter-comparisons; however, station 5 had an atypical substrate and appeared responsive to wave action in Keg Lake. In general, the data indicate that the bottom-dwelling organisms have been adversely affected only in a localized area immediately downstream of the Balmer Creek-Chukuni River confluence. A total taxa of nine at site 2b, immediately downstream of Balmer Creek, was less than half the number observed at the control sites, despite a strong similarity in flow, depth, substrate, and vegetation among the sites. Of particular interest is the almost total absence of any molluscs, a group which is very susceptible to mine wastes. At stations 3 and 4, a sharp increase in the diversity of organisms to near natural levels was noted. Also, at stations 3 and 4, increases were observed in the Mayfly, Hexagenia; Midge larvae, Chironomidae; Coleoptera, Elmidae; Amphipod, Hyalella azteca and a number of leech species.



The reduction of taxa and total individuals at station 5 on the Chukuni River cannot be fully explained at present. This phenomenon may be related to differences in substrate and flows.

Macroinvertebrates collected from sites on Red and Keg Lakes (Table 8) indicate a diverse aquatic community typical of waters in this region. Although there is a significant difference in mean water depth between Red Lake and Keg Lake, the number of taxa was similar. There are, however, three times as many macroinvertebrates per square metre in Keg Lake, owing to the presence of Pontoporeia affinis, an organism that favors waters deeper than 3-4 metres. Pontoporeia affinis is also present in Red Lake at sites of greater average water depth than that shown in the survey (MOE, 1974).

#### PHYTOPLANKTON

Results of identification and enumeration conducted on the single samples taken from Red, Keg and Balmer Lakes are shown in Table 9 in the form of presence and dominance in each lake. Although one sample from each lake is not definitive, some interpretation may be drawn.

The total number of genera found in Red Lake (32) and Keg Lake (33) signifies a balanced community. However, in Balmer Lake, only 10 taxa were present. This is a 66 percent decrease from that of Red and Keg Lakes in numbers of taxa found.

Dominance by different taxa from lake to lake has indicated differences in water quality. The reduction in numbers of taxa present in Balmer Lake demonstrates that a normal phytoplankton community is unable to inhabit Balmer Lake due to adverse water quality.

#### BIOASSAYS

Bioassays are designed to measure an organism's response after it is exposed to contaminated waters for a specified time.

Some bioassays are conducted on the same species at different life stages since the mature stage may not be at the most vulnerable stage to contaminants. Ideally, bioassays would be conducted "in situ" over the entire life cycle of the most sensitive organism in the ecosystem. In reality, however, this approach is impractical for the following reasons.

- (a) Wastes are generally complex mixtures of toxicants which act "in concert" on biota. A definitive understanding of each toxicant's contribution to the total toxicity on an annual basis is difficult to obtain, especially in waters where fluctuating conditions such as flow, temperature, and pH will affect the toxicity of different contaminants in various ways.
- (b) Because of (a), in contaminated ecosystems, the most sensitive organism is not usually known.
- (c) Logistical and financial limitations usually preclude intensive toxicological investigations. As previously mentioned in this study, the two bioassays utilized included a standard static 96-hour bioassay using rainbow trout fingerlings and an in situ bioassay utilizing clams, an organism with known sensitivity to mine wastes.

#### Static Bioassays

With the exception of the tailings effluent from Dickenson Mines Limited, all waters tested in the Balmer Creek and Chukuni River watershed (Figure 3) proved non-toxic to rainbow trout (Salmo gairdneri) over 96 hours. Tailings effluent samples, however, proved highly toxic, with total mortality occurring within five minutes in test concentrations with greater than 5 percent effluent. The following results indicate that the 96-hour LC<sub>50</sub> (50% mortality) test concentrations for rainbow trout were only 0.66 percent effluent.



MEDIAN LETHAL CONCENTRATION  
(LC<sub>50</sub>)

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| Time<br>(Hours) | Concentration<br>(% Effluent) |
|-----------------|-------------------------------|
| 4               | 0.74                          |
| 24              | 0.5 LC <sub>50</sub> 0.7      |
| 48              | 0.66                          |
| 96              | 0.66                          |

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The large difference in toxicity between Balmer Lake waters and those in the mining complex effluent must be related to dilution and natural purification processes of discharged materials. An examination of the physico-chemical characteristics of the effluent (Table 10) suggests that zinc, copper, nickel, arsenic, cyanide and ammonia are present in toxic quantities. Filtration had marginal effects on zinc, copper, and nickel concentrations and reduced arsenic levels only by a factor of approximately two. The complexity of aquatic chemistry twinned with the limited bioassay literature on these elements and/or complexes prevents an accurate ranking of toxicants in a decreasing order of importance; consequently, at present, one can only surmise that the aforementioned parameters, acting "in concert", have created extremely inhospitable conditions for most aquatic life. Significant modification of wastes through dilution, co-precipitation, sedimentation, and transformation processes must transpire, since waters taken from Balmer Lake were not acutely toxic to rainbow trout in 96 hours.

#### In Situ Bioassay

Results presented in Table 7 clearly indicate that toxic conditions exist for clams (Adontis grandis) in the Balmer Creek

watershed. Some time between two and four weeks after the bio-assay commenced, mortalities of 100 percent at sites 3 and 4 were recorded. No mortality was observed at other sites during the two-month experiment. The importance of losing cages to vandals at site 2 on June 26 was minimized by the survival of all organisms at station 5, the Chukuni River, downstream of the Balmer Creek site. Also, the experiment was run during times of highest water temperatures, when maximum stress due to high metabolic rates could be expected. The fact that all clams survived at site 5 does not imply that absolutely no adverse changes in water quality occurred due to the influx of Balmer Creek flows. A longer exposure may have induced death or chronic sublethal effects. Also, the complete life-cycle of the clams was not examined and other life stages may be more sensitive to contaminants from Balmer Creek. Nevertheless, the survival of these clams in the Chukuni River suggests that these waters do not form an unfavourable environment for most aquatic organisms.

#### MERCURY AND ARSENIC LEVELS IN WALLEYE

For many years, the Ministry of the Environment has been testing fish for possible contaminants to ensure that fish flesh is acceptable for public consumption. After all available data were examined, the potential contaminants of concern for the Red Lake area were arsenic and mercury. Arsenic and mercury results for walleye caught in Red and Keg Lakes are presented in Tables 11 and 12. No fish were obtained from Balmer Lake. Length and weight are also included since the well-established relationship between fish size and mercury contamination is evident in these populations. No similar relationship was observed for arsenic.

Generally, mercury concentrations in fish in both lakes appear typical of walleyes obtained from pristine lakes in north-western Ontario. Admittedly, there is a substantial range of mercury levels in biota for natural water bodies and, consequently, mercury loadings from Balmer Creek may have marginally increased body burdens in organisms. Since there is no

information on mercury levels in biota before the mining operations began, it is not possible to quantify any changes that may have occurred. The fact that mercury concentrations in walleye from Keg Lake (downstream of Balmer Creek) were, in general, lower than those in Red Lake suggests that mercury losses from Balmer Creek watershed under present conditions are not of concern. All walleye groups marked by an "A" are fit for unrestricted consumption. In Red and Keg Lakes, walleyes less than 46 centimetres (18 inches) and 56 centimetres (22 inches) respectively meet this criterion. Fish in the "B" category do have restrictions for both short-term (i.e. fishing holiday) and long-term exposure: meals should be limited to ten per week for a one-week vacation, five per week for two weeks, and four meals per week for three weeks. For long-term consumption, one meal per week is recommended. Children under 15 and women of child-bearing age should eat fish only from category "A". One meal is considered to be 226 grams (8 oz.) of boneless muscle tissue.

Although other species were not tested, a large data base in Ontario permits one to make certain reasonable assumptions for other species in these waters. In the majority of lakes tested, pike have generally comparable mercury levels with walleye, and species lower down the food chain, such as suckers and whitefish, have reduced mercury levels. Further information is available in A Guide To Eating Ontario Sports Fish, 1979, available at all Ministry of the Environment offices.

Arsenic concentrations in walleye analysed from both Red Lake and Keg Lake were, with minor exceptions, at least an order of magnitude lower than the maximum allowable limits of 5 ppm set by the Canadian Food and Drug Directorate for the sale of marine and freshwater animal products. Arsenic concentrations in walleye do not pose any consumption restrictions.

## CONCLUSIONS

1. Gold mining and processing operations by Campbell Red Lake Mines Limited and Dickenson Mines Limited have seriously impaired and continue to impair the waters of Balmer Lake and Balmer Creek. Impairment is manifested principally in the absence of normal aquatic communities. This is likely being caused by the observed high concentrations of arsenic, cyanide and a number of heavy metals including copper, zinc, nickel and cobalt. The effects of Balmer Creek waters on the Chukuni River appear to be minor.
2. The sediments of Balmer Lake and Balmer Creek are contaminated with a number of heavy metals including arsenic, chromium, copper, zinc and cobalt. Much of the sediment in Balmer Lake and Balmer Creek is derived from previously discharged tailings.
3. An evaluation of mercury levels in walleye collected from Red Lake and Keg Lake indicated that concentrations were typical of other northwestern Ontario waters and, therefore, do not represent an environmental concern.
4. Although Balmer Lake is not presently capable of supporting a normal aquatic community, it is expected that with additional waste treatment, the water quality at the outlet to Balmer Lake will meet the Provincial Water Quality Objectives (P.W.Q.O.) for the protection of aquatic life.
5. Meeting the P.W.Q.O. at the point of discharge from Balmer Lake will guarantee the protection of the Chukuni River and downstream waters from impairment and will result in progressive improvements in the ability of Balmer Creek to support a healthy community of aquatic organisms.

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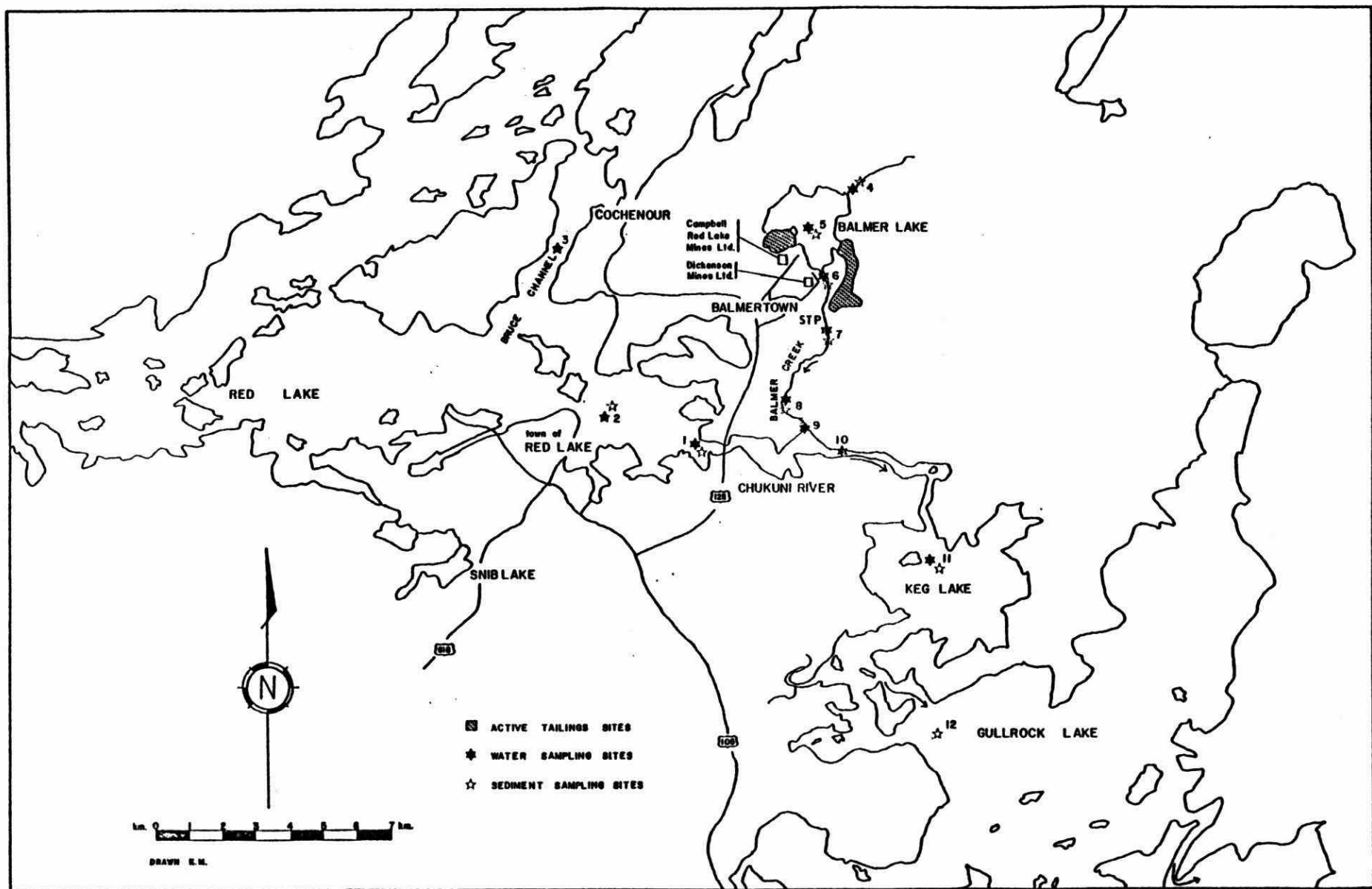


FIGURE 1. Water and sediment sampling sites in the Balmer Creek-Chukuni River system.



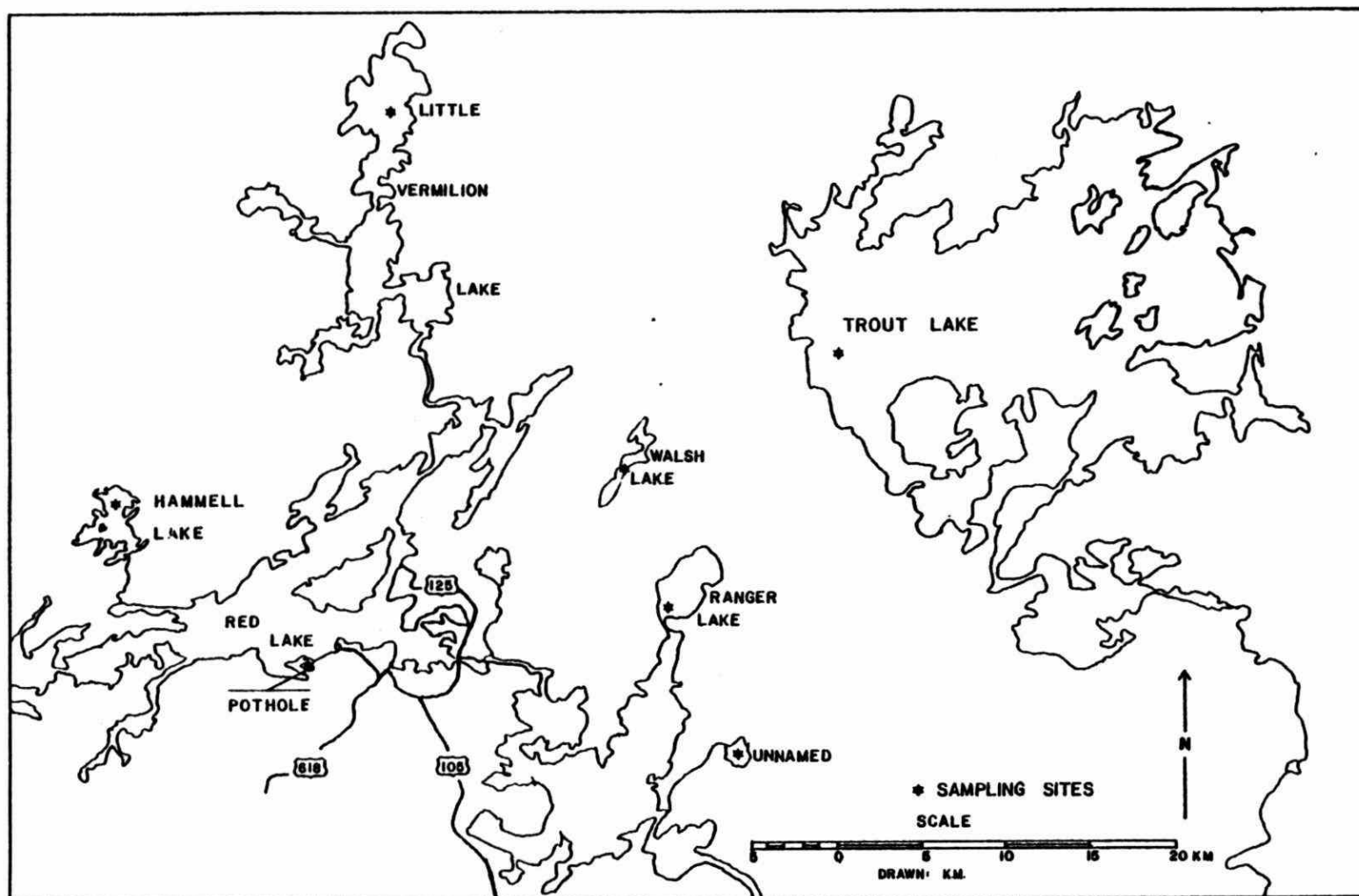


FIGURE 2. Water and sediment sampling sites in off-system lakes.

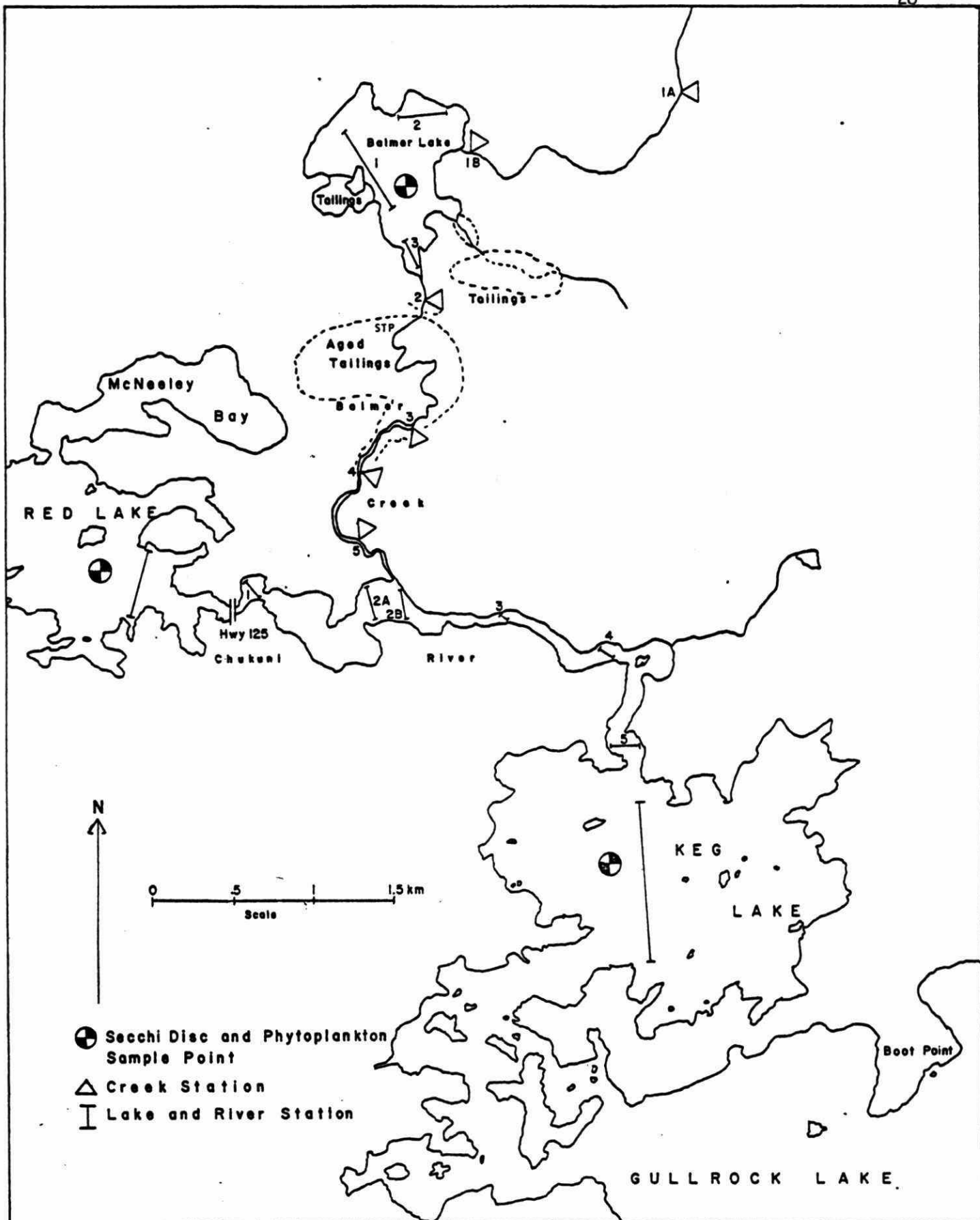


FIGURE 3. Macroinvertebrate and phytoplankton collection sites in the Balmer Creek-Chukuni River system.

FIGURE 4. Bioassay sites in the Balmer Creek-Chukuni River system.

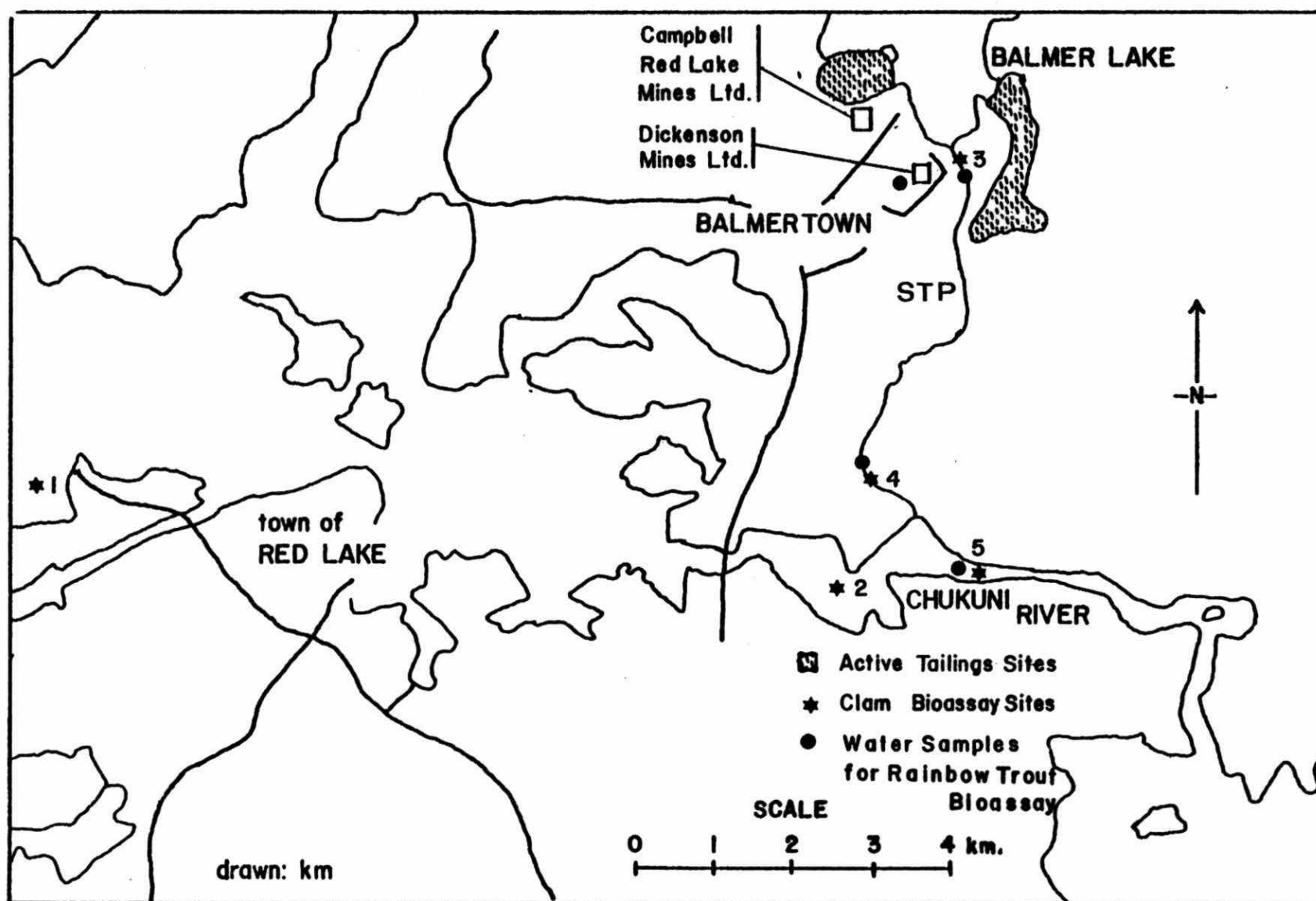


TABLE 1. Mean values for selected physico-chemical aquatic parameters at study sites for 1978-1979 study year.

| Location <sup>a</sup>                           | pH<br>(-log H <sup>+</sup> ) | Temp.<br>(°C) | Dissolved<br>Oxygen | Ammonia | Total<br>Kjeldahl | Nitrate | Nitrite | Total<br>Phosphorus | Soluble<br>Phosphorus | Turbidity<br>(F.T.U.) | Colour<br>(Hazen<br>Units) | Total<br>Solids |
|-------------------------------------------------|------------------------------|---------------|---------------------|---------|-------------------|---------|---------|---------------------|-----------------------|-----------------------|----------------------------|-----------------|
| 1. Chukuni R.,<br>Hwy. 125                      | 6.9                          | 8.5           | 11.2                | < .01   | .44               | .002    | < .04   | .021                | .006                  | 1.2                   | 32                         | 72              |
| 2. Red Lake<br>Howey Bay                        | 6.7                          | 9.0           | 11.2                | < .01   | .41               | .002    | < .04   | .017                | .005                  | 1.2                   | 30                         | 48              |
| Red Lake,<br>Bruce Channel                      | 7.3                          | 8.0           | 11.1                | < .01   | .46               | .002    | < .03   | < .014              | .003                  | 1.1                   | >38                        | 60              |
| 4. Balmer Creek,<br>upstream<br>Balmer Lake     | 6.9                          | 10.1          | 9.2                 | < .01   | .51               | .007    | < .05   | .043                | .027                  | 1.9                   | >70                        | 115             |
| 5. Balmer Lake                                  | 7.7                          | 10.6          | 8.6                 | .83     | .77               | 2.4     | .07     | .25                 | .25                   | 13.5                  | >70                        | 290             |
| 6. Balmer Lake<br>outlet                        | 7.4                          | 8.2           | 8.7                 | .76     | 1.9               | 2.7     | .03     | .29                 | .25                   | 12.3                  | >70                        | 410             |
| 7. Balmer Creek<br>downstream of<br>Balmer Lake | 7.6                          | 8.6           | 9.6                 | 1.4     | 2.2               | 2.2     | .04     | .46                 | .41                   | 17.0                  | >65                        | 390             |
| 8. Balmer Creek<br>upstream<br>Chukuni River    | 7.2                          | 8.1           | 8.0                 | .60     | 1.7               | 2.0     | .06     | .42                 | .35                   | 8.2                   | >70                        | 310             |
| 9. Balmer Creek<br>mouth                        | 7.3                          | 8.8           | 8.5                 | .89     | 2.1               | 1.7     | .03     | .39                 | .31                   | 14.0                  | >70                        | 290             |
| 10. Chukuni River<br>downstream<br>Balmer Creek | 6.6                          | 8.2           | 10.9                | < .05   | .47               | < .08   | < .01   | .034                | .013                  | 2.2                   | 35                         | 58              |
| 11. Keg Lake,<br>1 m                            | 7.0                          | 10.6          | 10.6                | < .02   | .45               | .04     | < .01   | .028                | .011                  | 2.2                   | 27                         | 43              |
| Keg Lake,<br>22 m                               | 6.7                          | 8.5           | 8.4                 | < .02   | .44               | .10     | .01     | .034                | .017                  | 2.7                   | 30                         | 65              |

TABLE 1. (Continued)

| Location                                        | Susp.<br>Solids | Conductivity<br>(µmhos/cm) | Alk. | Sulphate | Total<br>Coliform <sup>b</sup> | Fecal<br>Coliform <sup>b</sup> | Cyanide | Mang.  | Iron | Mercury<br>(µg/l) | Zinc   | Copper | Nickel |
|-------------------------------------------------|-----------------|----------------------------|------|----------|--------------------------------|--------------------------------|---------|--------|------|-------------------|--------|--------|--------|
| 1. Chukuni R.,<br>Hwy. 125                      | 1.8             | 62                         | 29   | 3.2      | 15                             | < 4                            | < .01   | .008   | .11  | < .05             | < .004 | < .003 | < .002 |
| 2. Red Lake<br>Howey Bay                        | 1.3             | 61                         | 23   | 3.2      | 37                             | < 4                            | < .01   | < .006 | .07  | < .05             | < .003 | < .002 | < .001 |
| 3. Red Lake,<br>Bruce Channel                   | 2               | 58                         | 22   | 2.7      | 14                             | < 4                            | < .02   | .001   | .17  | < .05             | < .002 | < .009 | < .001 |
| 4. Balmer Creek,<br>upstream<br>Balmer Lake     | 4               | 81                         | 34   | 4.3      | 51                             | < 4                            | < .01   | .028   | .67  | < .05             | < .002 | < .008 | < .001 |
| 5. Balmer Lake                                  | 12              | 350                        | 49   | 56       | < 9                            | < 4                            | .30     | .11    | 1.39 | < .06             | .16    | .51    | .45    |
| 6. Balmer Lake<br>outlet                        | 8.3             | 470                        | 55   | 79       | < 430                          | < 27                           | .29     | .12    | .95  | < .06             | .17    | .44    | .44    |
| 7. Balmer Creek<br>downstream of<br>Balmer Lake | 25              | 480                        | 72   | 61       | < 86                           | < 32                           | .34     | .14    | 2.5  | .07               | .17    | .36    | .24    |
| 8. Balmer Creek<br>upstream<br>Chukuni River    | 8.3             | 420                        | 78   | 52       | 136                            | 24                             | .27     | .13    | .71  | < .06             | .09    | .23    | .23    |
| 9. Balmer Creek<br>mouth                        | 14              | 380                        | 67   | 48       | 360                            | 26                             | .28     | .11    | 1.8  | < .08             | .13    | .32    | .30    |
| 10. Chukuni River<br>downstream<br>Balmer Creek | 4.0             | 70                         | 24   | 4.8      | 7                              | < 9                            | < .01   | .027   | .20  | < .05             | .009   | < .023 | < .015 |
| 11. Keg Lake,<br>1 m                            | 3.0             | 66                         | 24   | 4.8      | < 9                            | < 4                            | < .02   | .015   | .14  | < .05             | .005   | < .015 | < .105 |
| Keg Lake,<br>22 m                               | 3.7             | 67                         | 23   | 4.5      | -                              | -                              | < .01   | .028   | .24  | .27               | .011   | .015   | .092   |

TABLE 2. Selected physico-chemical characteristics for seven undeveloped lakes in the Red Lake study area, August 16, 1978.

| Parameters <sup>a</sup>   | Location <sup>b</sup>  |             |              |                               |             |              |               |                |               |
|---------------------------|------------------------|-------------|--------------|-------------------------------|-------------|--------------|---------------|----------------|---------------|
|                           | Little Vermilion (1 m) | Walsh (1 m) | Ranger (1 m) | Unnamed (near Gullrock) (1 m) | Trout (1 m) | Trout (35 m) | Hammell (1 m) | Hammell (30 m) | Pothole (1 m) |
| pH (-log H <sup>+</sup> ) | 7.4                    | 7.4         | 7.5          | 8.3                           | 7.8         | 7.4          | 7.5           | 6.7            | 8.2           |
| Suspended solids          | 3                      | 5           | 10           | 5                             | 1           | 2            | 1             | 3              | 2             |
| Total phosphorus (ug/l)   | 16                     | 33          | 59           | 27                            | 5           | 4            | 4             | 6              | 10            |
| Conductivity (umhos/cm)   | 46                     | 61          | 78           | 143                           | 69          | 65           | 35            | 37             | 72            |
| Sulphate                  | 2.8                    | 3.1         | 2.1          | 2.2                           | 1.2         | 1.2          | 2.0           | 1.7            | 1.4           |
| Hardness                  | 26                     | 30          | 38           | 70                            | 28          | 30           | 14            | 20             | 30            |
| Alkalinity                | 18                     | 24          | 34           | 69                            | 29          | 29           | 14            | 18             | 20            |
| Colour (Hazen)            | >70                    | >70         | >70          | 30                            | <5          | <5           | <5            | <5             | 5             |
| Dissolved oxygen          | 9.0                    | 8.4         | 8.4          | 7.3                           | 6.9         | 3.9          | 8.2           | 6.3            | 7.2           |
| Secchi disc (m)           | 2.0                    | 1.1         | 0.7          | 1.7                           | 4.8         | -            | 4.0           | -              | N/A           |

<sup>a</sup>All values in mg/l except as specified.

<sup>b</sup>Location - see also Figure 2.

TABLE 2. (Continued)

| Parameters <sup>a</sup> | Location                     |                |                 |                                     |                |                 |                  |                   |                  |
|-------------------------|------------------------------|----------------|-----------------|-------------------------------------|----------------|-----------------|------------------|-------------------|------------------|
|                         | Little<br>Vermilion<br>(1 m) | Walsh<br>(1 m) | Ranger<br>(1 m) | Unnamed<br>(near Gullrock)<br>(1 m) | Trout<br>(1 m) | Trout<br>(35 m) | Hammell<br>(1 m) | Hammell<br>(30 m) | Pothole<br>(1 m) |
| Iron (mg/l)             | .30                          | .18            | .43             | .61                                 | .028           | .037            | .019             | .076              | .063             |
| Manganese               | .012                         | .017           | .021            | .072                                | .002           | .002            | .002             | .001              | .024             |
| Lead                    | 8                            | 5              | .005            | .005                                | .005           | .005            | .005             | .005              | .005             |
| Copper                  | 29                           | 27             | 9               | 27                                  | 47             | 19              | 3                | 7                 | <1               |
| Cobalt                  | <1                           | <1             | <1              | 1                                   | <1             | <1              | <1               | <1                | <1               |
| Cadmium                 | <1                           | <1             | <1              | 1                                   | <1             | 1               | <1               | <1                | <1               |
| Nickle                  | <1                           | <1             | <1              | <1                                  | <1             | <1              | <1               | 1                 | <1               |
| Zinc                    | 8                            | 3              | 3               | 2                                   | 3              | 4               | 1                | 4                 | 3                |
| Arsenic                 | 2                            | 13             | 15              | 7                                   | <1             | 1               | 1                | <1                | 5                |
| Mercury                 | <.05                         | <.05           | <.05            | <.05                                | <.05           | <.05            | <.05             | .05               | <.05             |
| Strontium               | 19                           | 28             | 33              | 38                                  | 30             | 30              | 20               | 20                | 20               |
| Aluminum (mg/l)         | .11                          | .07            | .42             | .041                                | <.05           | .35             | .05              | .06               | <.05             |
| Barium                  | 8                            | 16             | 13              | 25                                  | <20            | <20             | <20              | <20               | <20              |
| Vanadium                | <3                           | <3             | 2               | <2                                  | <2             | <2              | <2               | <2                | <2               |
| Selenium                | 1                            | <1             | <1              | <1                                  | <1             | 1               | <1               | <1                | <1               |

<sup>a</sup>All values in ug/l except as specified.

TABLE 3. Results for selected elements (mg/kg) for Keg and Gullrock Lake sediments, July, 1978.

| Lake     | Depth<br>(cm) | LOI<br>(%) | As   | Cu | Ni | Pb |
|----------|---------------|------------|------|----|----|----|
| Keg      | 0-5           | 5.0        | .92  | 44 | 37 | 14 |
|          | 5-10          | 4.9        | .21  | 19 | 26 | 6  |
|          | 10-15         | 5.0        | .11  | 21 | 26 | 5  |
|          | 15-20         | 5.6        | .08  | 25 | 29 | 6  |
|          | 0-5           | 5.1        | 2.20 | 80 | 50 | 28 |
|          | 5-10          | 4.6        | .29  | 19 | 24 | 8  |
|          | 10-15         | 4.5        | .09  | 14 | 22 | 7  |
|          | 0-5           | 8.6        | 1.50 | 61 | 48 | 18 |
|          | 5-10          | 8.8        | .36  | 31 | 33 | 10 |
|          | 10-15         | 9.6        | .23  | 34 | 37 | 10 |
| Gullrock | 0-5           | 9.3        | 2.40 | 77 | 62 | 17 |
|          | 5-10          | 8.9        | .50  | 43 | 40 | 10 |
|          | 10-15         | 10.0       | .24  | 31 | 35 | 10 |
|          | 15-20         | 10.0       | .17  | 36 | 38 | 9  |



TABLE 4. Selected results for sediments (mg/kg dry wt.) in the Red Lake study area, July, 1979.

| Site <sup>a</sup>                         | Core Section (cm) | LOI (%) | As <sup>b</sup> |       | Ni (ppm) | Pb (ppm) |
|-------------------------------------------|-------------------|---------|-----------------|-------|----------|----------|
|                                           |                   |         | E.S. (%)        | A.A.  |          |          |
| 1. Chukuni R. at Hwy. 125                 | 0-5               | 1.1     | < .1            | .0005 | 14       | 21       |
|                                           | 5-10              | 2.3     | < .1            | .0005 | 43       | 21       |
|                                           | 10-15             | 2.4     | < .1            |       | 58       | 18       |
|                                           | 15-20             | 2.1     | < .1            | .005  | 45       | 22       |
|                                           | 20-25             | 2.2     | < .1            |       | 66       | 18       |
| 2. Red Lake near Howey Bay                | 0-5               | 9.3     | < .1            |       | 35       | 27       |
|                                           | 5-10              | 7.0     | < .1            |       | 39       | 86       |
|                                           | 10-15             | 8.7     | < .1            |       | 35       | 56       |
| 3. Red Lake Bruce Channel                 | 0-5               | 11.8    | < .1            |       | 18       | 15       |
|                                           | 5-10              | 19.8    | < .1            |       | 25       | 10       |
|                                           | 10-15             | 19.5    | < .1            | .0006 | 48       | 20       |
|                                           | 15-20             | 18.6    | < .1            | .0006 | 31       | 5        |
| 4. Balmer Creek upstream of Balmer Lake   | 0-5               | 21.7    | < .1            |       | 27       | 12       |
|                                           | 5-10              | 19.2    | < .1            |       | 26       | 14       |
|                                           | 10-15             | 17.6    | < .1            |       | 23       | 13       |
|                                           | 15-20             | 19.4    | < .1            |       | 27       | 14       |
|                                           | 20-25             | 20.6    | < .1            |       | 28       | 12       |
| 5. Balmer Lake                            | 0-5               | 14.7    | .2              | .16   | 520      | 75       |
|                                           | 5-10              | 20.5    | < .1            |       | 107      | 26       |
|                                           | 10-15             | 17.7    | .4              |       | 795      | 81       |
|                                           | 15-20             | 19.6    | < .1            |       | 92       | 24       |
|                                           | 20-25             | 18.9    | < .1            | .01   | 134      | 32       |
| 6. Balmer Lake outlet                     | 0-5               | 7.2     | .3              |       | 371      | 98       |
|                                           | 5-10              | 7.0     | .3              |       | 316      | 86       |
|                                           | 10-15             | 3.8     | < .1            |       | 87       | 25       |
|                                           | 15-20             | 3.8     | < .1            |       | 68       | 25       |
| 7. Balmer Creek downstream of Balmer Lake | 0-5               | 7.2     | .3              |       | 371      | 130      |
|                                           | 5-10              | 7.0     | .3              |       | 316      | 112      |
|                                           | 10-15             | 3.8     | < .1            |       | 87       | 82       |
|                                           | 15-20             | 3.8     | < .1            |       | 68       | 66       |
| 8. Balmer Creek upstream of Chukuni River | 0-5               | 1.3     | .4              |       | 320      | 190      |
|                                           | 5-10              | 1.1     | .5              |       | 270      | 158      |
|                                           | 10-15             | 1.3     | .5              |       | 290      | 136      |
|                                           | 15-20             | 1.0     | .4              | .39   | 320      | 115      |

TABLE 4. (Continued)

| Site <sup>a</sup> | Core<br>Section<br>(cm) | LOI<br>(%) | As <sup>b</sup> |      | Ni<br>(ppm) | Pb<br>(ppm) |
|-------------------|-------------------------|------------|-----------------|------|-------------|-------------|
|                   |                         |            | E.S.<br>(%)     | A.A. |             |             |
| 11. Keg Lake      | 0-5                     | 12.6       | < .1            |      | 122         | 85          |
|                   | 5-10                    | 12.4       | < .1            |      | 70          | 25          |
|                   | 10-15                   | 12.3       | < .1            |      | 51          | 23          |
|                   | 15-20                   | 12.5       | < .1            |      | 44          | 15          |
|                   | 20-25                   | 12.3       | < .1            |      | 44          | 10          |
| 12. Gullrock L.   | 0-5                     | 14.0       | < .1            |      | 41          | 19          |
|                   | 5-10                    | 13.4       | < .1            |      | 36          | 7           |
|                   | 10-15                   | 12.6       | < .1            |      | 36          | 15          |
|                   | 15-20                   | 11.8       | < .1            |      | 18          | 15          |

<sup>a</sup>See also Figure 1.

<sup>b</sup>E.S. - Emission spectroscopy.

A.A. - Atomic absorption spectroscopy.

TABLE 5. Selected results for sediments (mg/kg) from seven undeveloped lakes in the Red Lake watershed.

| Lake <sup>a</sup> | Core Section (cm) | L.O.I. <sup>b</sup> (%) | Ni (ppm) | Pb (ppm) |
|-------------------|-------------------|-------------------------|----------|----------|
| Vermilion         | 0-5               | 8.2                     | 38       | 16       |
|                   | 5-10              | 7.8                     | 40       | 17       |
|                   | 10-15             | 7.4                     | 37       | 15       |
|                   | 15-20             | 7.4                     | 46       | 20       |
| No Name           | 0-5               | 17.3                    | 45       | 19       |
|                   | 5-10              | 16.2                    | 45       | 17       |
|                   | 10-15             | 15.2                    | 42       | 14       |
|                   | 15-20             | 15.0                    | 43       | 14       |
| Ranger            | 0-5               | 12.1                    | 36       | 18       |
|                   | 5-10              | 5.6                     | 39       | 13       |
|                   | 10-15             | 2.5                     | 39       | 14       |
|                   | 15-20             | 1.8                     | 41       | 14       |
| Hammel            | 0-5               | 41.2                    | 41       | 10       |
|                   | 5-10              | 14.1                    | 34       | 14       |
|                   | 10-15             | 21.6                    | 39       | 11       |
| Pothole           | 0-5               | 50.0                    | 22       | 16       |
|                   | 5-10              | 46.5                    | 31       | 32       |
|                   | 10-15             | 39.0                    | 35       | 18       |
|                   | 15-20             | 30.0                    | 36       | 11       |
| Walsh             | 0-5               | 20.3                    | 30       | 22       |
|                   | 5-10              | 20.7                    | 16       | 11       |
|                   | 10-15             | 19.5                    | 39       | 16       |
|                   | 15-20             | 18.9                    | 38       | 15       |
| Trout             | 0-5               | 13.7                    | 40       | 24       |
|                   | 5-10              | 12.4                    | 38       | 18       |
|                   | 10-15             | 12.6                    | 40       | 21       |
|                   | 15-20             | 11.6                    | 38       | 18       |

<sup>a</sup>See Figure 2.

<sup>b</sup>Loss of ignition (x organic content).

TABLE 6. Survival frequencies of caged clams at selected sites, June 13, 1978 to August 17, 1978.

| Site <sup>a</sup>                                     | % Survival           |                 |         |           |
|-------------------------------------------------------|----------------------|-----------------|---------|-----------|
|                                                       | June 13 <sup>b</sup> | June 26         | July 18 | August 17 |
| Red Lake                                              | 100                  | 100             | 100     | 100       |
| Chukuni River, upstream of Balmer Creek               | 100                  | NA <sup>c</sup> | NA      | NA        |
| Balmer Creek at Balmer Lake outflow                   | 100                  | 100             | 0       | 0         |
| Balmer Creek, 150 m upstream of Chukuni River         | 100                  | 100             | 0       | 0         |
| Chukuni River, 1 kilometre downstream of Balmer Creek | 100                  | 100             | 100     | 100       |

<sup>a</sup>See Figure 3 also.

<sup>b</sup>Commencement of bioassay.

<sup>c</sup>Clam cages vandalized.

TABLE 7. Macroinvertebrates collected from Balmer Lake and Balmer Creek, August, 1978.

| Taxa                       | Station | Balmer Lake |   |   | #1A | #1B  | Balmer Creek |       |      | 4    | 5 |
|----------------------------|---------|-------------|---|---|-----|------|--------------|-------|------|------|---|
|                            |         | 1           | 2 | 3 |     |      | 2            | 3     |      |      |   |
| MAYFLY (EPHEMEROPTERA)     |         |             |   |   |     |      |              |       |      |      |   |
| Ephemera Sp.               |         |             |   |   |     |      |              |       |      |      |   |
| Hexagenia Sp.              |         |             |   |   |     |      |              |       |      |      |   |
| Baetinae Sp.               |         |             |   |   | P   | 3.8  |              |       |      |      |   |
| Caeninae Sp.               |         |             |   |   |     |      |              |       |      |      |   |
| Ametropinae Sp.            |         |             |   |   | P   |      |              |       |      |      |   |
| CADDISFLY (TRICHOPTERA)    |         |             |   |   |     |      |              |       |      |      |   |
| Agrypnia Sp.               |         |             |   |   | P   |      |              |       |      |      |   |
| Limnephilidae Sp.          |         |             |   |   | P   |      |              | P     |      |      |   |
| Limnephilus Sp.            |         |             |   |   |     |      |              |       |      |      |   |
| Hydropsyche Sp.            |         |             |   |   |     |      |              |       |      |      |   |
| Molanna Sp.                |         |             |   |   |     |      |              |       |      |      |   |
| Phylocentropus Sp.         |         |             |   |   |     | 3.8  |              |       |      |      |   |
| Polycentropus Sp.          |         |             |   |   |     |      |              |       |      |      |   |
| Neophylax Sp.              |         |             |   |   |     |      |              |       |      |      |   |
| Platycentropus Sp.         |         |             |   |   |     | 3.8  |              |       |      |      |   |
| Triadenodes Sp.            |         |             |   |   |     | 3.8  |              |       |      |      |   |
| Sp. unident Sp.            |         |             |   |   |     |      |              |       |      |      |   |
| DRAGONFLY (ODONATA)        |         |             |   |   |     |      |              |       |      |      |   |
| Libellulidae Sp.           |         |             |   |   |     | 7.6  | P            |       |      |      |   |
| Gomphus Sp.                |         |             |   |   |     |      |              |       |      |      |   |
| DAMSELFLY (ODONATA)        |         |             |   |   |     |      |              |       |      |      |   |
| Zygoptera Sp.              |         |             |   |   |     |      |              |       |      |      |   |
| MEGALOPTERA                |         |             |   |   |     |      |              |       |      |      |   |
| Sialis Sp.                 |         |             |   |   |     |      |              |       |      |      |   |
| DIPTERA                    |         |             |   |   |     |      |              |       |      |      |   |
| Chironomidae I (Large) Sp. |         |             |   |   | P   | 34.1 | P            | 228.0 | 18.9 | 15.2 |   |
| Chironomidae II Sp.        |         |             |   |   |     |      |              |       |      |      |   |
| Heleidae Sp.               |         |             |   |   | P   |      |              |       | 7.6  | 7.6  |   |
| Chaoborus Sp.              |         |             |   |   |     |      |              |       |      |      |   |
| Simuliidae Sp.             |         |             |   |   | P   |      |              | 3.8   |      |      |   |
| HEMIPTERA                  |         |             |   |   |     |      |              |       |      |      |   |
| Corixidae Sp.              |         |             |   |   |     | 3.8  | P            |       |      |      |   |
| Gerridae Sp.               |         |             |   |   |     |      | P            |       |      |      |   |
| UNIDENTIFIED               |         |             |   |   |     |      |              |       |      |      |   |
| Sp.                        |         |             |   |   | P   | 11.4 | P            | 3.8   |      |      |   |
| COLEOPTERA                 |         |             |   |   |     |      |              |       |      |      |   |
| Gyrinidae Sp.              |         |             |   |   |     | 3.8  |              |       |      |      |   |
| Elmidae Sp.                |         |             |   |   |     |      |              |       |      |      |   |
| Sp.                        |         |             |   |   | P   | 11.4 |              |       |      |      |   |



TABLE 7. (Continued)

| Taxa                             | Station | Balmer Lake |       |       | #1A | #1B   | Balmer Creek |     |      | 4    | 5    |
|----------------------------------|---------|-------------|-------|-------|-----|-------|--------------|-----|------|------|------|
|                                  |         | 1           | 2     | 3     |     |       | 2            | 3   |      |      |      |
| NUMBER OF SAMPLES/STATION        |         | 10          | 5     | 5     | 2Q  | 5     | 2Q           | 5   | 5    | 5    | 5    |
| MEAN SAMPLE DEPTH/m              |         | 2.8         | 2.8   | 2.2   | -   | 0.6   | -            | 1.6 | 1.8  | 1.3  | 1.3  |
| TOTAL TAXA                       |         | 0.0         | 0.0   | 0.0   | 13  | 16    | 8            | 2   | 3    | 3    | 3    |
| TOTAL INDIVIDUALS/m <sup>2</sup> |         | 0.0         | 0.0   | 0.0   | -   | 234   | -            | 227 | 49.2 | 75.8 | 75.8 |
| SUBSTRATE                        |         | T           | T/M/D | M/D/S | -   | M/D/V | -            | T   | T/D  | T/D  | T/D  |

T = Tailings.

M = Mud, Silt.

D = Detritus (woody matter, decayed vegetation).

S = Sand.

V = Vegetation.

C = Clay.

Q = Qualitative Sample.







TABLE 8. (Continued)

| Taxa                             | Station | Red<br>Lake | CR<br>#1 | CR<br>#2a | CR<br>#2b | CR<br>#3 | CR<br>#4 | CR<br>#5 | Keg<br>Lake |
|----------------------------------|---------|-------------|----------|-----------|-----------|----------|----------|----------|-------------|
| NUMBER OF SAMPLES/STATION        |         | 5           | 5        | 5         | 5         | 10       | 5        | 5        | 10          |
| MEAN SAMPLE DEPTH/m              |         | 3.7         | 5.7      | 2.0       | 2.6       | 1.4      | 3.0      | 2.0      | 7.8         |
| TOTAL TAXA                       |         | 15          | 18       | 19        | 9         | 19       | 11       | 6        | 14          |
| TOTAL INDIVIDUALS/m <sup>2</sup> |         | 364.0       | 1061.0   | 739.0     | 288.0     | 597.0    | 2117.0   | 239.0    | 1233.0      |
| SUBSTRATE                        |         | C/S/G       | C/S      | M/C/D     | C/S/G     | M/C/D    | M/D/S/C  | D/M/C    | M/S/C       |

C = Clay.

S = Sand.

G = Gravel.

M = Mud, Silt.

D = Detritus (woody matter, decayed vegetation).

T = Tailings.

V = Vegetation.

TABLE 9. Chlorophyll analysis, phytoplankton presence and dominance in one sample collected from each of Red, Keg and Balmer Lakes, August 17, 1978.

|                          | Red Lake | Keg Lake | Balmer Lake |                      | Red Lake | Keg Lake | Balmer Lake |
|--------------------------|----------|----------|-------------|----------------------|----------|----------|-------------|
| DEPTH OF SAMPLE (metres) | 6.0      | 4.2      | 2.0         |                      |          |          |             |
| CHLOROPHYLL <u>A</u>     | 1.3      | 0.2      | 2.5         |                      |          |          |             |
| PHYTOPLANKTON            |          |          |             |                      |          |          |             |
| CYANOPHYCEAE             |          |          |             | CHLOROPHYCEAE        |          |          |             |
| Anabaena                 | P 1st    | P 1st    |             | Botryococcus         | P        |          |             |
| Aphanizomenon            | P 6th    | P 2nd    |             | Chlamydomonas        | P        | P        | P 6th       |
| Aphanothece              | P        | P        |             | Closterium           | P        |          |             |
| Chroococcus              | P        | P        |             | Coelastrum           | P        | P        |             |
| Coelosphaerium           | P        | P        |             | Cosmarium            |          | P        |             |
| Lyngbya                  | P 3rd    | P        |             | Dictyosphaerium      | P        | P        | P 1st       |
| Merismopedia             | P        | P        |             | Golenkinia           |          | P        |             |
| Oscillatoria             | P        | P        | P 5th       | Monoraphidium        | P        |          |             |
|                          |          |          |             | Oocystis             | P        | P        |             |
| DINOPHYCEAE              |          |          |             | Paramastix           |          | P        |             |
| <u>UNID</u> Dinophyceae  | P 5th    | P 6th    | P 4th       | Scenedesmus          | P        |          | P           |
|                          |          |          |             | Tetradron            |          | P        |             |
| CRYPTOPHYCEAE            |          |          |             |                      |          |          |             |
| Cryptomonas              | P        | P 4th    |             | BACILLARDIOPHYCEAE   |          |          |             |
| Katablepharis            | P        | P        |             | Asterionella         | P        | P        |             |
| Rhodomonas               | P        | P        |             | Cyclotella           |          | P        | P           |
|                          |          |          |             | Fragilaria           | P 4th    |          |             |
| CHRYSTOPHYCEAE           |          |          |             | Melosira             | P        | P 3rd    |             |
| <u>UNID</u> Chrysomonads | P        | P        | P 3rd       | Nitzschia            |          |          | P           |
| Chrysochromulina         | P        | P        |             | Rhizosolenia         |          | P        |             |
| Chrysophyte <u>cysts</u> | P        | P        |             | Stephanodiscus       | P        | P 5th    |             |
| <u>UNID</u> Chrysophyte  | P        | P        |             | Synedra              | P        | P        | P           |
| Dinobryon                | P        | P        | P 2nd       | Tabellaria           | P 2nd    | P        |             |
| Monochrysis              | P        |          |             |                      |          |          |             |
|                          |          |          |             | TOTAL TAXA PRESENT   | 32       | 33       | 10          |
|                          |          |          |             | ZOO PLANKTON PRESENT |          |          |             |
|                          |          |          |             | Protozoans           | P        |          |             |
|                          |          |          |             | Ciliates             | P        | P        |             |

TABLE 10. Physico-chemical characteristics of tailings effluent from Dickenson Mines Ltd., August 16, 1978.

| Parameter <sup>a</sup>    | Raw Water | Filtered<br>(.45μ) |
|---------------------------|-----------|--------------------|
| Zinc                      | 6.6       | 5.1                |
| Copper                    | 6.8       | 6.8                |
| Nickle                    | 6.0       | 5.5                |
| Iron                      | 380       | 7.7                |
| Arsenic                   | 47        | 25                 |
| pH (-log H <sup>+</sup> ) | 9.7       |                    |
| Calcium                   | 114       |                    |
| Sodium                    | 105       |                    |
| Potassium                 | 33        |                    |
| Magnesium                 | 1         |                    |
| Hardness                  | 288       |                    |
| Alkalinity                | 149       |                    |
| Sulphate                  | 89        |                    |
| Chloride                  | 241       |                    |
| Unionized ammonia         | 2.5       |                    |
| Total cyanide             | 50        |                    |

<sup>a</sup>In mg/l unless otherwise indicated.

TABLE 11. Mercury and arsenic concentrations in Walleye epaxial muscle, Red Lake, 1978.

| Length<br>(cm) | Weight<br>(g) | Hg<br>(ppm) | As<br>(ppm) |
|----------------|---------------|-------------|-------------|
| 48.5           | 1192          | 0.42        | .13         |
| 47.0           | 1050          | 1.10        | .52         |
| 43.0           | 710           | 0.34        | .08         |
| 42.0           | 681           | 0.31        | .14         |
| 35.0           | 341           | 0.25        | .08         |
| 31.0           | 255           | 0.38        | .08         |
| 30.0           | 227           | 0.21        | .24         |
| 28.0           | 170           | 0.14        | .04         |
| 26.5           | 142           | 0.15        | .08         |
| 24.5           | 114           | 0.17        | .10         |
| 21.0           | 85            | 0.17        | .15         |
| 52.5           | 1362          | 0.67        | .32         |
| 49.0           | 1192          | 0.54        | .16         |
| 47.0           | 964           | 0.33        | .05         |
| 44.0           | 738           | 0.29        | .07         |
| 39.0           | 510           | 0.51        | .05         |
| 39.0           | 510           | 0.22        | .07         |
| 38.0           | 482           | 0.26        | .06         |

MERCURY CONCENTRATION IN RELATION TO FISH LENGTH

| SPECIES | <u>SIZE RANGE IN INCHES</u> |     |      |       |       |       |       |       |       |    |
|---------|-----------------------------|-----|------|-------|-------|-------|-------|-------|-------|----|
|         | 6                           | 6-8 | 8-10 | 10-12 | 12-14 | 14-18 | 18-22 | 22-26 | 26-30 | 30 |
| WALLEYE | -                           | A   | A    | A     | A     | A     | B     | B     | -     | -  |

A = Mercury concentration <0.5 ppm.

B = Mercury concentration 0.5-1.0 ppm.

- = Mercury data not available for this size.

TABLE 12. Mercury and arsenic concentrations in Walleye epaxial muscle, Keg Lake, 1978.

| Length<br>(cm) | Weight<br>(g) | Hg<br>(ppm) | As<br>(ppm) |
|----------------|---------------|-------------|-------------|
| 55.0           | 1391          | 0.62        | .18         |
| 51.0           | 1277          | 0.83        | .15         |
| 51.0           | 1192          | 0.29        | .08         |
| 49.0           | 1192          | 0.35        | .16         |
| 47.0           | 937           | 0.35        | .10         |
| 46.0           | 908           | 0.21        | .08         |
| 43.0           | 766           | 0.36        | .11         |
| 42.0           | 681           | 0.30        | .10         |
| 38.0           | 539           | 0.16        | .05         |
| 36.0           | 426           | 0.14        | .07         |
| 38.0           | 454           | 0.16        | .11         |
| 35.0           | 340           | 0.18        | .11         |
| 33.0           | 363           | 0.20        | .04         |
| 32.0           | 255           | 0.29        | .03         |
| 30.0           | 227           | 0.14        | .03         |
| 29.0           | 199           | 0.11        | .10         |
| 28.0           | 199           | 0.12        | .02         |
| 26.0           | 578           | 0.16        | .11         |
| 26.0           | 578           | 0.12        | .13         |
| 23.0           | 94            | 0.22        | .06         |
| 20.0           | 57            | 0.11        | .10         |

MERCURY CONCENTRATION IN RELATION TO FISH LENGTH

SIZE RANGE IN INCHES

| SPECIES | 6 | 6-8 | 8-10 | 10-12 | 12-14 | 14-18 | 18-22 | 22-26 | 26-30 | 30 |
|---------|---|-----|------|-------|-------|-------|-------|-------|-------|----|
| WALLEYE | - | A   | A    | A     | A     | A     | A     | B     | -     | -  |

A = Mercury concentration <0.5 ppm.

B = Mercury concentration 0.5-1.0 ppm.

- = Mercury data not available for this size.

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